



Future Electric Ship and Power & Energy

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Outline

Naval Energy Vision/Strategy

Future All Electric Ship

First Navy Hybrid Electric Ship

S&T Issues/Challenges

**Power Generation, Energy Storage, Power
Distribution & Control, and Thermal**

Closing Thoughts



Naval Energy Strategy



Energy Security

Energy security is critical to our mission success. We will safeguard our energy infrastructure and shield ourselves from a volatile fuel supply. The Navy and Marine Corps value energy independence.

Energy Efficiency

Energy efficiency increases our mission effectiveness. We extend our tactical range and minimize operational risks, saving time, money, and lives. We are all responsible for energy efficiency.

Environmental Stewardship

Environmental stewardship protects our mission capabilities. We reduce our dependence on fossil fuels and minimize carbon pollution. The workforce promotes a healthy environment for a sustainable future.

**SECNAV Goal
October 2009**



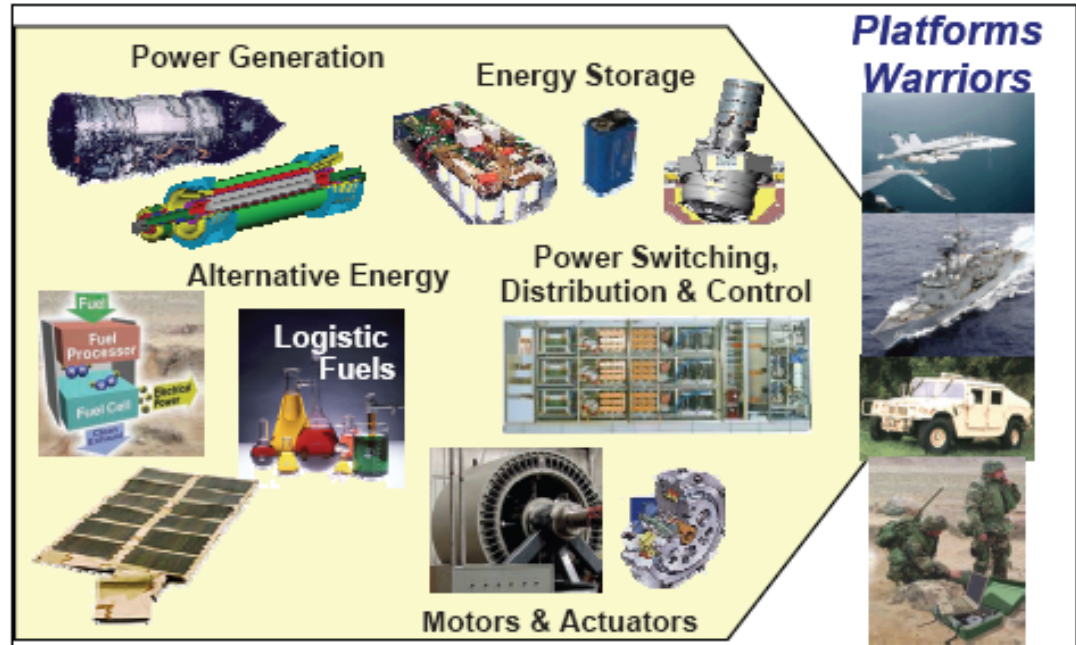
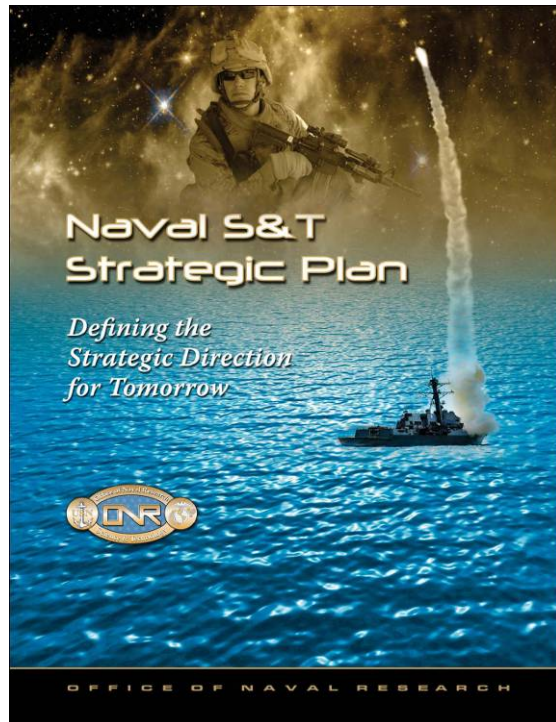
By 2016, the Navy will sail a **“Great Green Fleet”** composed of nuclear ships, surface combatants with hybrid electric power systems using biofuel, and aircraft flying only on biofuels. “



Power & Energy Impacts EVERY Navy & USMC Mission



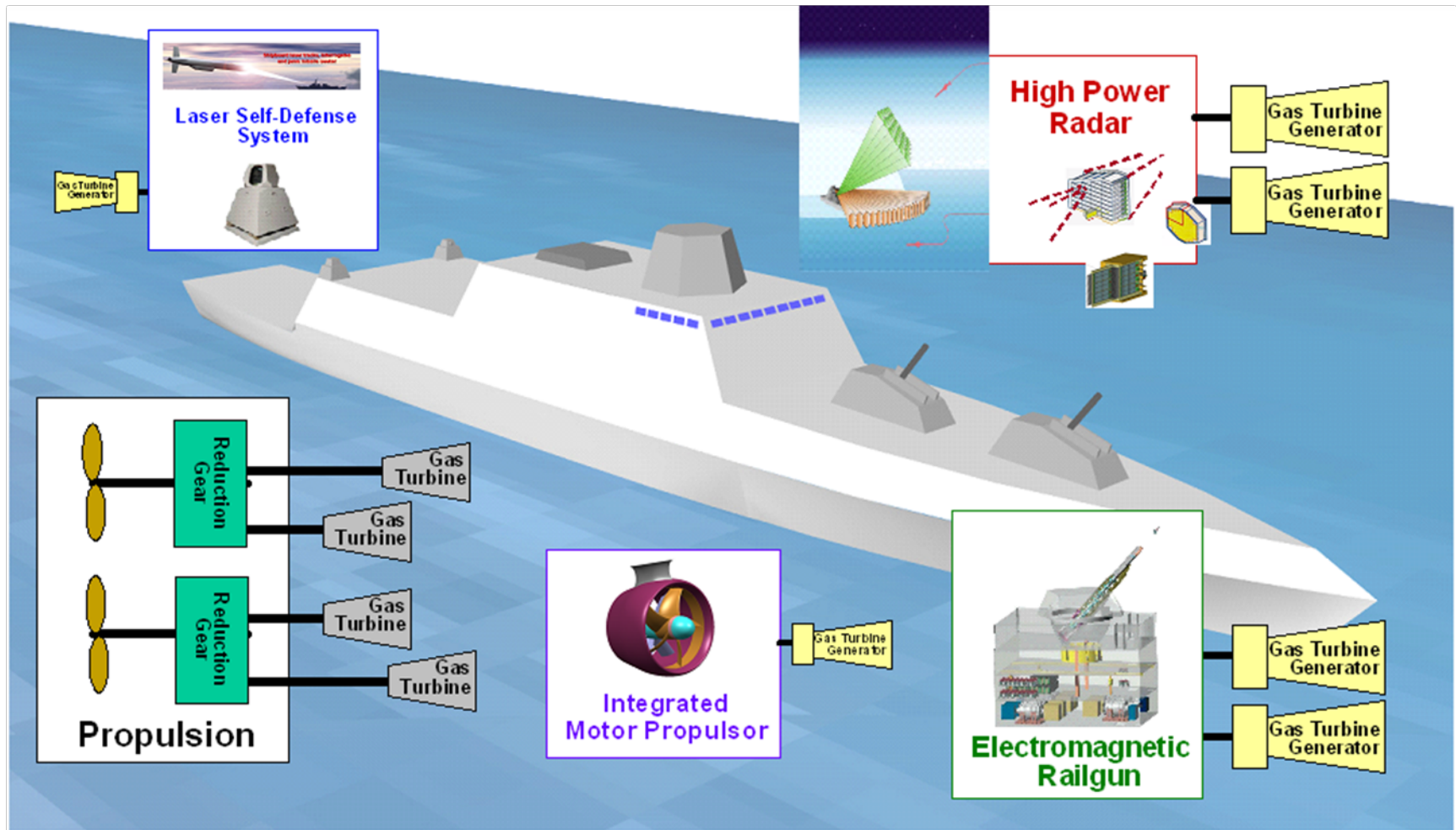
Naval Power & Energy S&T Focus Area



Vision: Increase Naval forces' freedom of action through energy security and efficient power systems, to provide desired power at the manned/unmanned platform, system, and personal levels

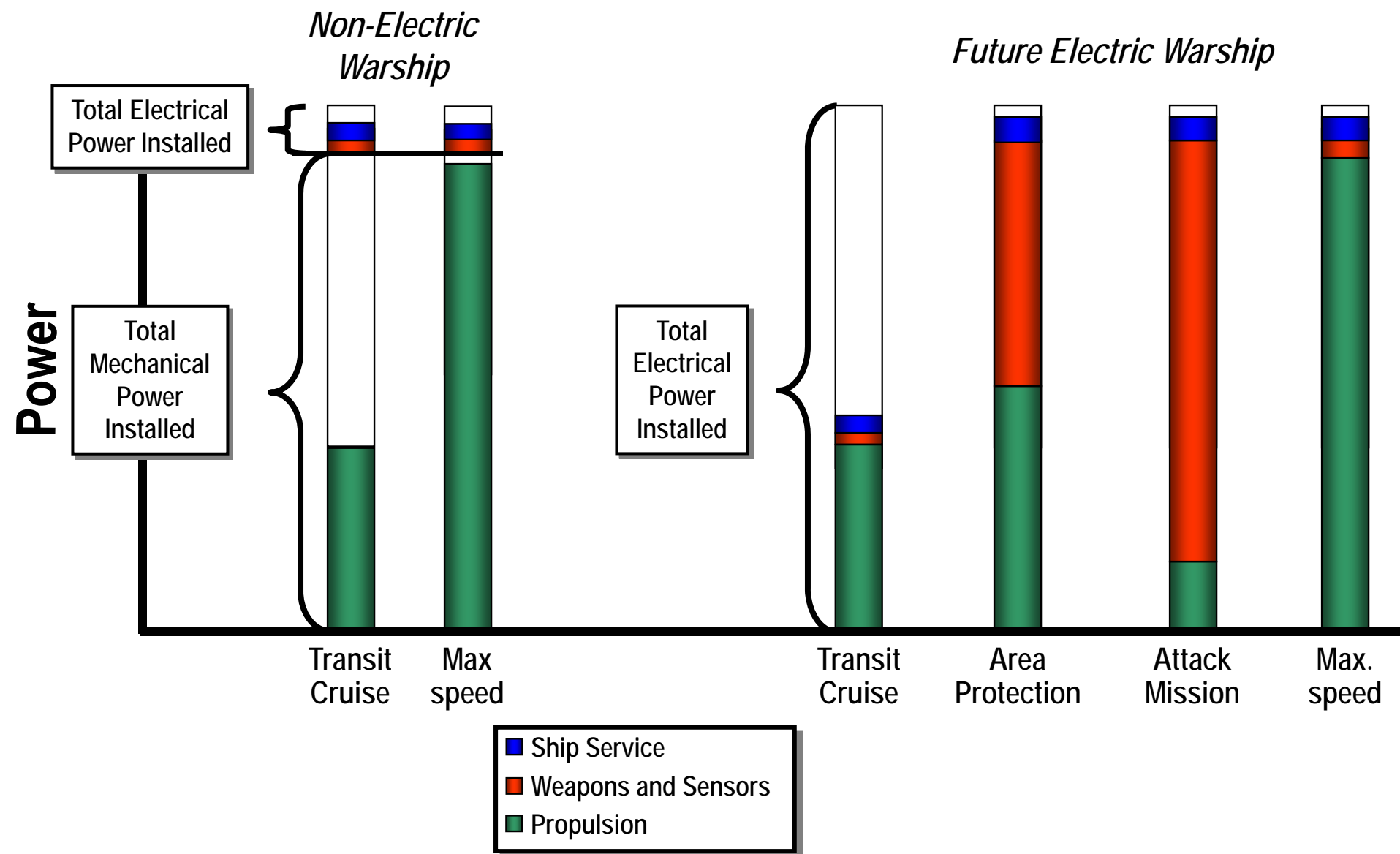
What We Would Like to Avoid...

...Dedicated Power for each Mission System





Unlock the Propulsion Power

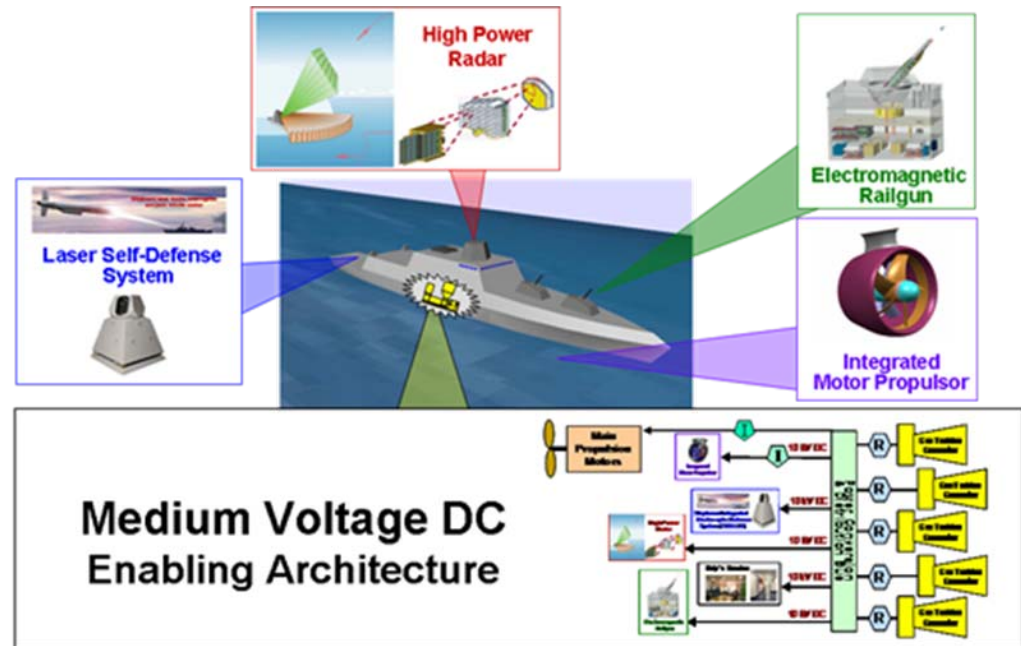


Electric Warship Vision

Integrates and develops system technologies and advanced electrical power systems that enables a quantum leap in both fuel efficiency and seamless transition of power to multiple high power loads.

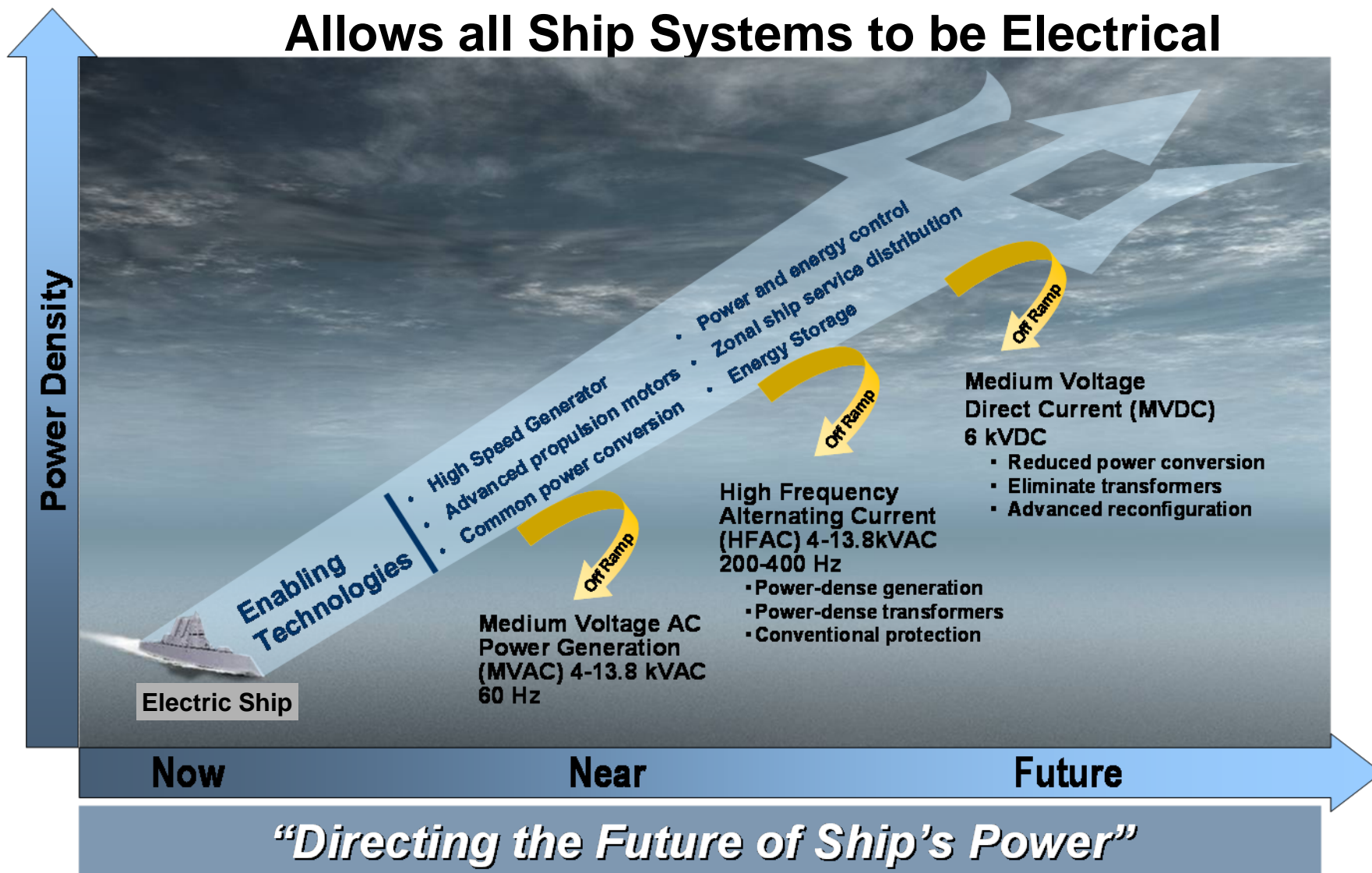
Challenges:

- Power density
- Duration to transition power between different high power loads
- System efficiency
- Power ramp rate
- Power continuity



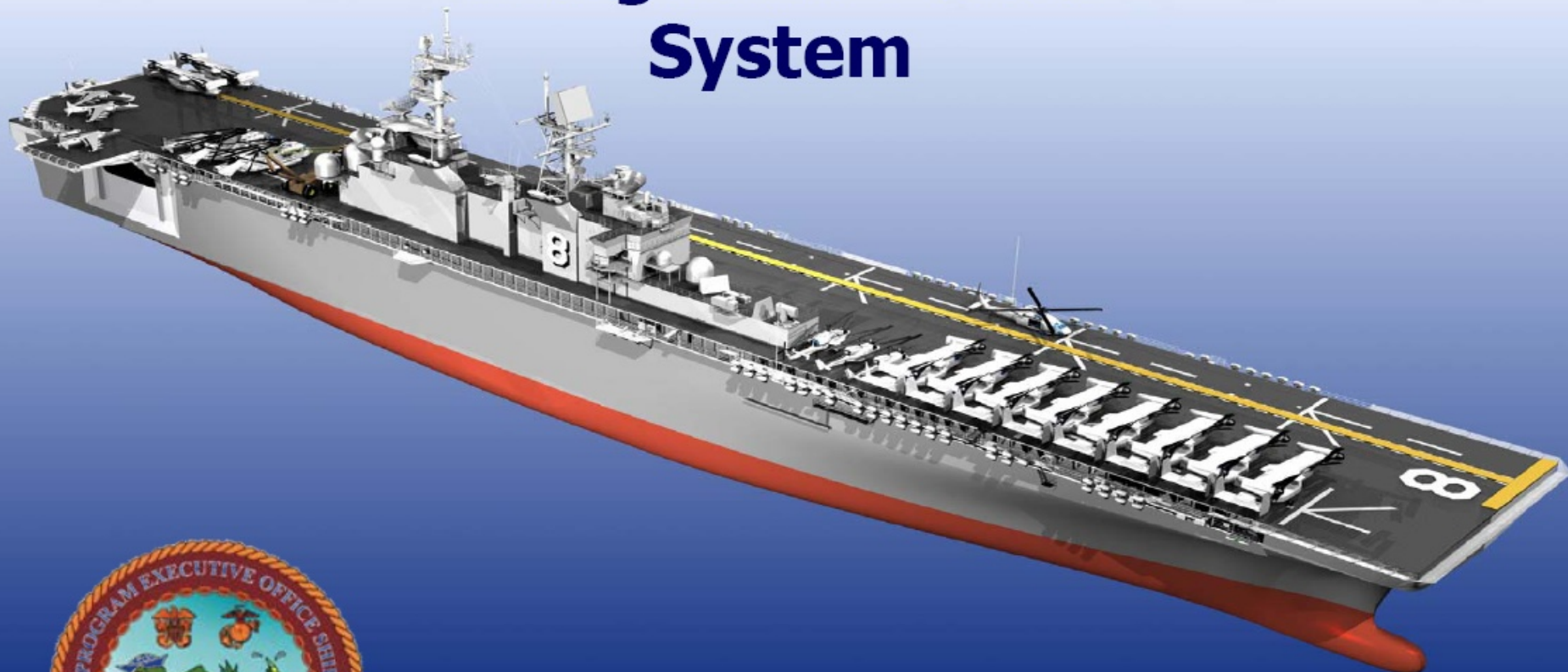
Next Generation Integrated Power Systems

Allows all Ship Systems to be Electrical



LHD 8 – MAKIN ISLAND

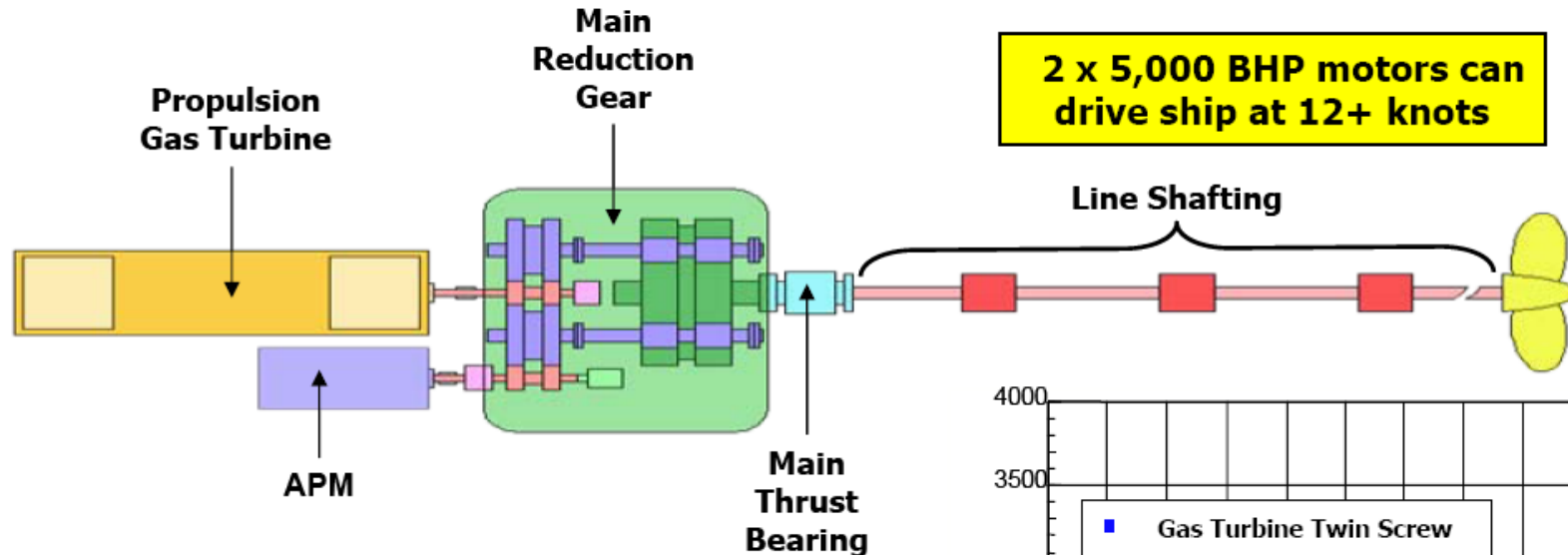
First Step Towards Integrated Power System



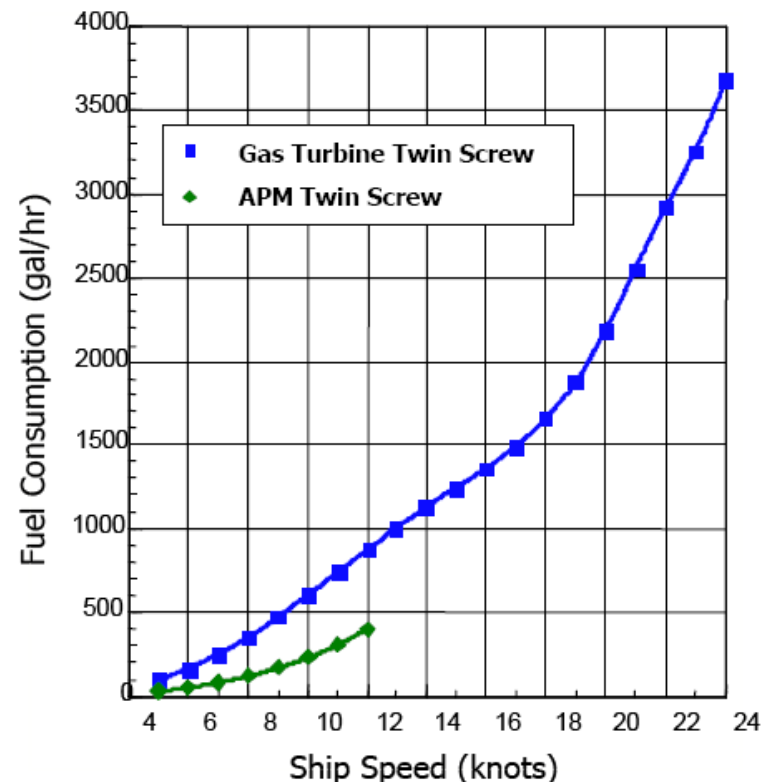
[http://en.wikipedia.org/wiki/USS_Makin_Island_\(LHD-8\)](http://en.wikipedia.org/wiki/USS_Makin_Island_(LHD-8))

The First Navy Hybrid Electric Drive!

Propulsion Plant Arrangement: Motivation (Fuel Economy!)



- ◆ Reduces time gas turbine spends at low power levels
- ◆ Annual fuel savings over \$500,000, life cycle fuel savings over \$21,000,000
- ◆ Additional savings resulting from reduced maintenance and lower manning



Advanced Naval Power Research Sub Area

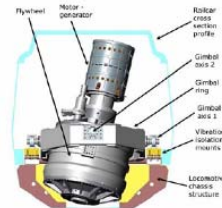
Vision: To increase Naval forces freedom of action through the development of efficient power systems.

1. Power Generation:

- Fuel Cells & Fuel Reforming
- Advanced Generators

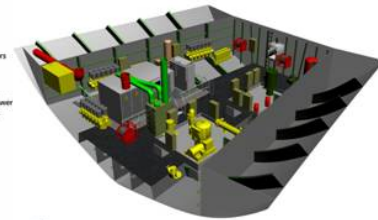
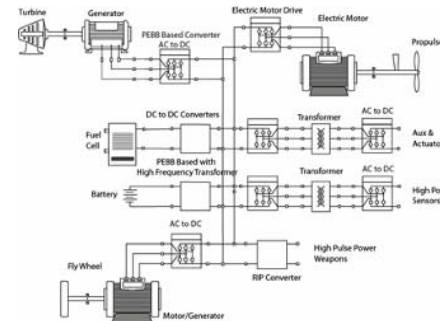
2. Energy Storage:

- Batteries
- Capacitors
- Flywheels



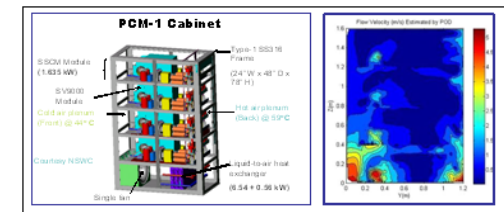
3. Distribution & Control:

- Architecture
- Switching & Conditioning



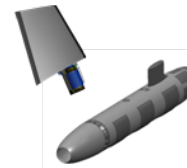
4. Heat Transfer, Thermal Management:

- High Waste Heat Flux Removal
- Adv. Chiller Technologies / HVAC



5. Motor & Actuators:

- Motors
- Actuators
- Electro-Mechanical Devices



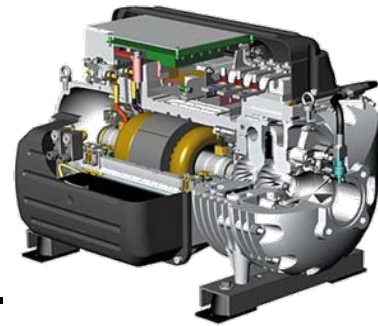


Science and Technology - Issues/Challenges

Goal: Increased Capability, Maximum Efficiency

Power Generation:

- Electrical and mechanical engineering of high-speed generators
- Efficient transformation of fuel into electrical energy (i.e. Fuel cells)
- Material reliability, failure mechanisms



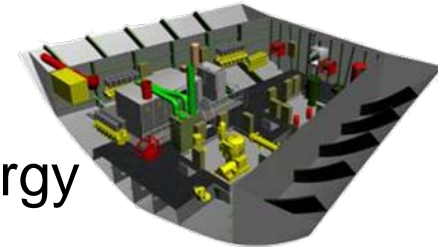
Energy Storage:

- Advanced materials (high purity, high dielectric breakdown)
- Increased energy density and high temperature operation



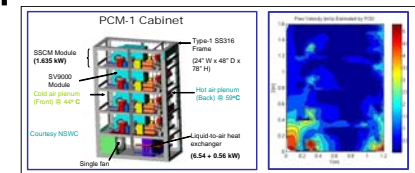
Distribution & Control:

- Real-time state estimation of complex systems
- Control laws to direct the dynamic flow of power & energy
- Physics-based component- & systems-level M&S and design tools
- Improved yield and cost of power electronics



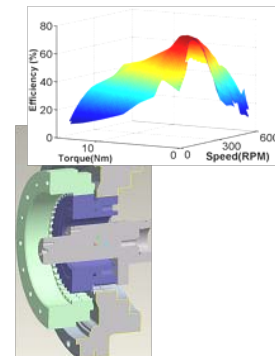
Heat Transfer, Thermal Management:

- Isothermal cooling; Integral & scalable cooling concepts
- Physics-based models
- High thermal conductivity materials; Phase change materials



Electromechanical Systems:

- High Power-Density
- Open source validated design tools for electromechanical systems

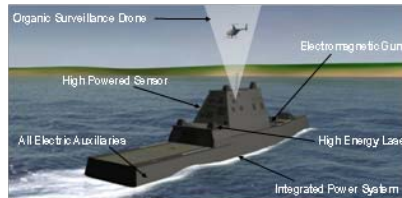


Wide Band Gap Semi-Conductors

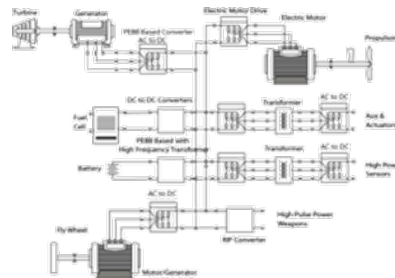
Objectives:

- Physics based modeling and simulation capability to understand and predict complex system behavior; materials development for high power packages
- Physics behind integrated high power switch failure mechanisms (voltage breakdown, electromigration, current filamentation)
- Understand and discovering ways to reduce thermal migration effects in power devices and packages; understand effects of thermal cycling on packaged integrated circuits

Investment in wide band gap semi-conductors essential for enabling *All Electric Ship* concept



Research essential for powering large/diverse electrical loads and electronic warfare systems.



Challenges:

- 10-20 kV switching capability
- Large diameter SiC Substrate Wafers
- High Yield Systems
- Cost Reduction
- Next Generation P/E



Energy Storage

Energy storage is a key enabling technology for electric ship, unmanned vehicle, and person portable power applications

ONR is investing in a range of activities:

- Dielectric, battery, and ultra-capacitor **materials** development
- Storage system **design, development, optimization, and demonstration**
- System **architecture, integration, and controls**
- **Safety and environmental testing** to support Fleet use approval requirements

Focus on higher power and energy densities in safe, more compact, lightweight formats

Battery Materials

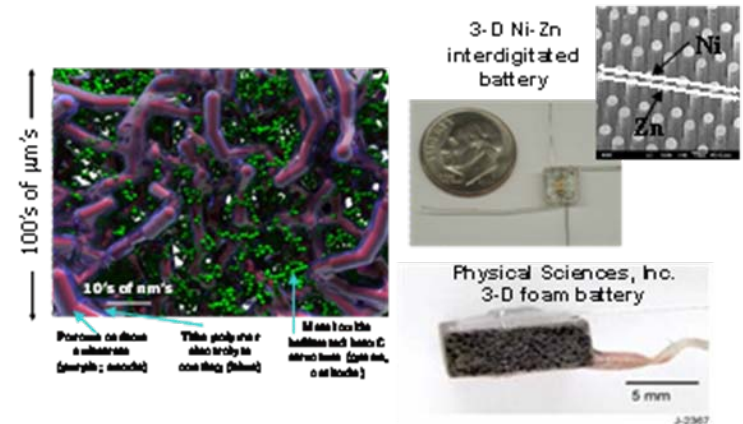
Objective: Enhanced power-dense energy storage for safe, confident use in a variety of Naval applications

Technical Challenges

- Developing thin, conformal separator/ electrolyte coatings over non-line-of-site surfaces (providing adequate ionic conductivity without shorting)
- **3-D characterization and modeling to quantitatively understand battery electrode structures and properties**
- Understanding and quantifying the role of electrochemical double layer overlap as a function of electrode spacing
- Understanding and controlling degradation and failure mechanisms for safer, extended operation

Approach

- Develop and demonstrate the scaling of nanoscopic and microscopic 3-D battery designs to support macro-scale 3-D structural batteries for parasitic weight reduction
- Develop and demonstrate novel materials and battery architectures that significantly increase electrochemical storage and charge rates
- Develop fundamental tools for characterizing and designing practical battery electrodes



Naval Impact

- High energy batteries and systems with enhanced safety and performance
- **3-D Micro- and Nano-batteries for NEMS/MEMS microsystems and sensors**
- **Structural 3-D batteries for significant reductions in volume and weight**
- High energy density, neutrally buoyant, pressure tolerant batteries for air-independent applications

Capacitor Materials

Objective: Capacitors that provide ultrahigh power/ energy densities and cycling stability for extended service life in pulsed power (millisecond discharge times), high temperature and auxiliary power applications

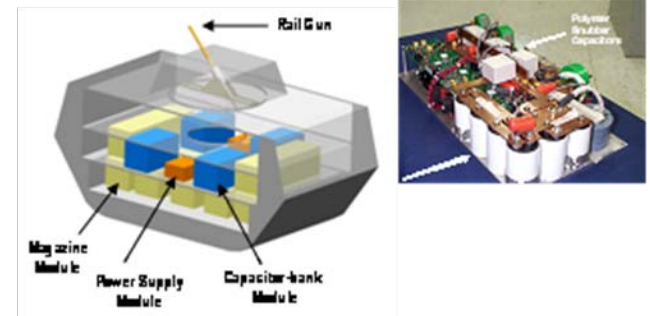
Technical Challenges

- Increasing energy storage density (permittivity & breakdown threshold) and maximizing charge/ discharge rates
- Understanding and controlling roles of phase morphology and of interfaces in complex hybrid systems at all appropriate length and time scales
- Understanding and controlling dielectric break-down mechanisms; identifying/ designing benign failure modes
- Scaling up promising materials, processing and packaging technologies for consistent, predictable properties

Approach

- Develop and quantify fundamental understanding of dielectric charge storage & transfer in complex ceramic/polymer systems
- Develop enhanced polymer-based dielectric films and processing technologies for very high pulse power rates
- Develop novel inorganic dielectrics and hybrids with $>200^{\circ}\text{C}$ capability for power conditioning
- Develop hybrid polymer/ceramic dielectric materials and devices, super-capacitors and electrochemical capacitors for auxiliary power applications

*Power Electronic
Inverters & Converters*



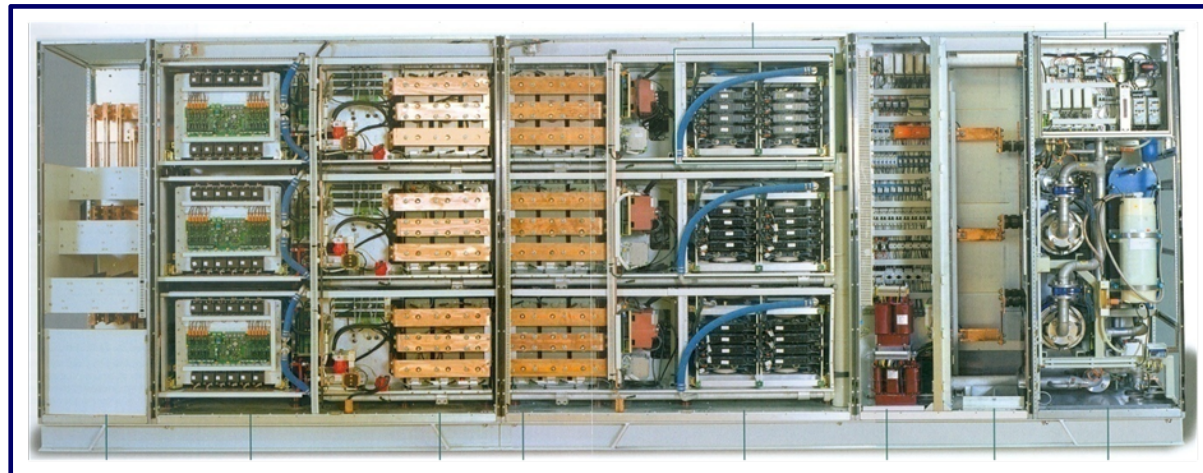
Naval Impact

- 10X reduced weight and volume allocation for capacitor banks for pulsed power loads
- Increased discharge rates for pulsed power
- Reliable, energy dense systems for power conditioning and auxiliary power requirements

Power Control & Distribution

POWER CONTROL & DISTRIBUTION

- Architecture
- Switching & Conditioning



Objective:

- Design a ship electrical system architecture based on a main bus that distributes “rough” DC power throughout the ship & all associated control & protection systems.
- Develop & evaluate a ship-wide electrical system universal controller.
- Develop real-time & non-real-time modeling & simulation (M&S) techniques, including hardware-in-the-loop, to evaluate the controller.

Approach:

- Develop physics-based component models & M&S design & evaluation techniques
- Identify & investigate new materials & techniques

Products:

- Control & protection system requirements
- Robust M&S, evaluation & design capability
- Design guidance for a notional DC distribution system

Architectures

Objectives:

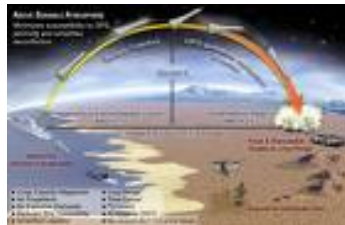
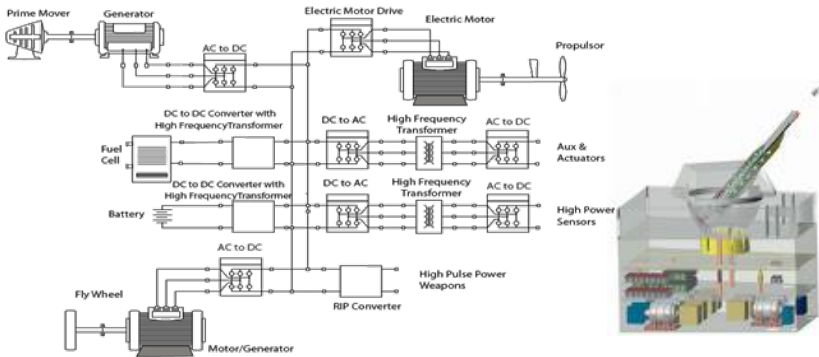
- **Electrical system architectures based on optimum power processing concepts to yield reduced size, weight, and cost**
- **Control & stability hierarchy to manage high-levels of power and energy for all operational conditions**

Challenges:

- **Reduce power charging**
- **Increased reliability and safety**
- **Greater utilization of finite shipboard energy resources**

Goals:

- **Rapid Recovery & Reconfiguration**
- **Dynamic Power Management**
- **Active Isolation**
- **Solid State – Silicon Carbide Based**
- **10kV Standards, Methods, & Tools**
- **DC 10kV components**

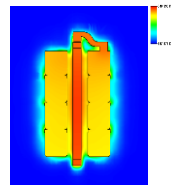
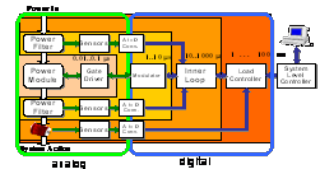
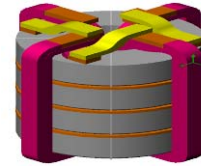
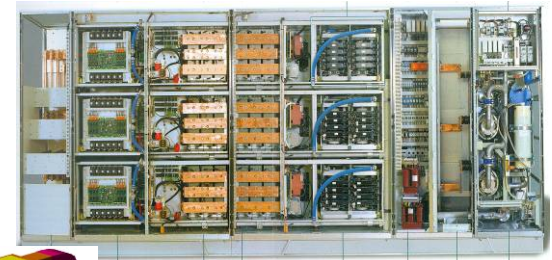
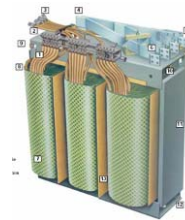


Compact Power Conversion Technologies

Objective:

Provide the power dense and highly efficient electrical backbone enabling high power demanding pulsed loads such as advanced radars, sensors and potentially directed energy weapons thru the development and demonstration of :

- Multifunction Power Converter
- Bi-Directional Power Converter
- Power Manager



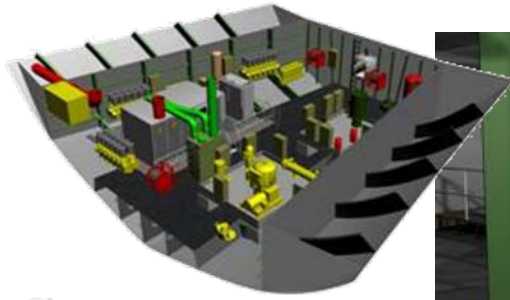
Challenges:

- Increased power density by a factor of 2-3
- Improved the efficiency of the power conversion system [~94-98%]

Eliminates the need for single application power and energy storage solutions. Minimize total power conversion through multi-functionality.



Fuel-Efficient Shipboard Fuel Cells



S&T Products:

- Improved fuel cell system efficiency to > 40%
- 3x improvement in reformer power density
- 65% fuel cell stack efficiency at 25% power & 55% at rated power

Objective:

To improve:

- Liquid-Phase De-sulfurization
- High power density reforming
- Fuel cell stacks
- Energy recovery & oxidation

Technical Challenges:

- High capacity liquid-phase de-sulfurization
- Effect of dense hydrogen separation membranes
- Improving reformer efficiencies
- Fundamental knowledge of fuel cell materials
- Fundamental knowledge of liquid fuel vortex combustor operation

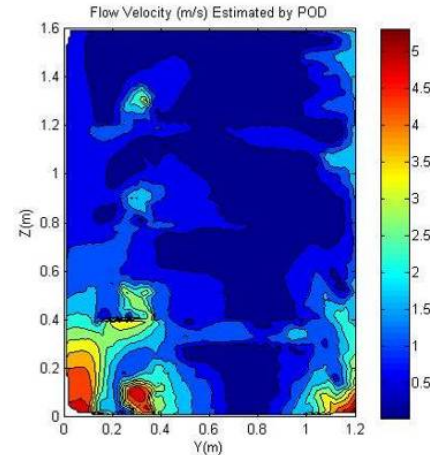
Technical Approach:

- Enhance sulfur adsorption bed capacities
- Develop and validate process models
- Demonstrate and validate fuel cell stack characteristics in the Navy environment

High Waste Heat Flux Removal

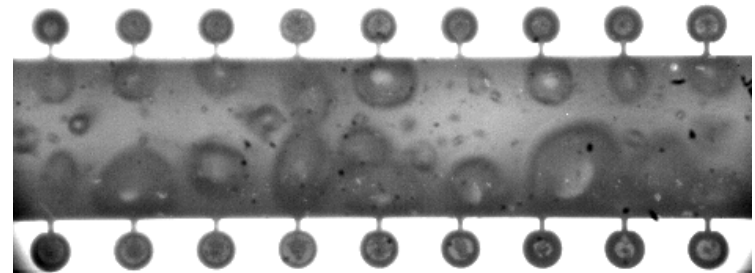
Objectives:

- Physics-based models of evaporative cooling, including heat transfer and critical heat flux
- Two phase flow in complex geometries
- Heat transfer through interfacial engineering
- Advanced thermal fluids for convective heat transfer
- High efficiency, compact, and light weight HVAC system architectures
- Alternative refrigeration systems for distributed cooling
- Waste heat reuse to for ship cooling and thermal energy storage



Challenges:

- Heat Transfer Coefficient (single-phase, two-phase)
- Increased Thermal Conductivity
- Increased Thermal Energy Storage





Closing Thoughts

Vision: Great Green Fleet

Near Term - Reduce vehicle petroleum use

Long Term - Increase alternative energy across DoN

Opportunities:

Engagement with Global S&T Community

Near-Term Topics of Collaboration:

Power Generation – High Speed Generator

Energy Storage – Batteries, Capacitors, and Fuel Cells,

Power Conversion – Multifunctional, Bi-Directional Power

Converter and its Devices

Physics Based Modeling & Simulation

Global S&T Partnering is key to success



Thank you very much!!!



Q & A

**This presentation materials were provided by:
Dr. John Pazik, ONR331, and CAPT. Lynn Petersen, NAVSEA, Electric Ship Office**

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